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Explosion parameters of methanol–air mixtures

Maria Mitu [a],*, Elisabeth Brandes [b]

[a] "Ilie Mugulescu" Institute of Physical Chemistry, Romanian Academy, 202 Spl. Independentei, 060021 Bucharest, Romania
[b] Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

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ABSTRACT

The evaluation of methanol as an alternative fuel requires, among other things, information and the systematic investigation of explosion parameters of methanol in air in various conditions. An experimental study of the explosive combustion of methanol–air mixtures at various initial conditions (temperatures, pressures and fuel/air ratios within the explosion limits) was performed in a closed vessel with central ignition. The explosion pressures and the rate of pressure rise were determined as a function of the fuel/air ratio at different initial temperatures and pressures. Based on these experimental data, the maximum explosion pressure and the maximum rate of pressure rise were determined as a function of pressure and temperatures. The deflagration index and also the laminar burning velocity were calculated from these data too. It was shown that the known temperature and pressure dependence of the maximum explosion pressure can also be assigned to the explosion pressures over more or less the whole fuel/air ratios investigated. Furthermore the same pressure dependence is valid for the rate of pressure rise, whereas within the temperature range investigated, a temperature dependence could not be found. The temperature influence on the burning velocity proposed in the literature holds for the received data of the current investigations.

1. Introduction

Methanol has been suggested as an attractive alternative to conventional fuels because of potential reductions in pollutant emissions and because methanol can be synthesized from a wide variety of feedstock and even garbage [1]. The evaluation of methanol as an alternative fuel requires, among other things, information and the systematic investigation of explosion characteristics of methanol in air in various conditions.

In the literature there are many mechanisms developed for methanol oxidation applicable to various ranges of temperatures, pressures and equivalence ratios [2–5]. Experimental studies have been carried out on the oxidation of methanol at different temperatures [6–11], shock tubes were used in these cases. Wiser and Hill [12] measured burning velocities in methanol–air mixtures using a horizontal tube. De Wilde and van Tiggelen [13] studied the concentration and temperature dependence of the burning velocity of premixed methanol–oxygen flames and proposed a simplified reaction mechanism. Other burning velocities of methanol–air mixtures were reported using different experimental techniques [14–19]. Koda [14] measured explosion pressures, unburned methanol and formaldehyde emissions from the combustion of methanol–water–air gaseous mixtures in a cylindrical vessel ($V = 0.8$ L, inner diameter/height = 1) as a function of concentration and water content. Zhang [20] studied the combustion characteristics of methanol–air/diluent premixed mixtures in a cylindrical vessel ($V = 5.5$ L inner diameter/height $\cong 1$). Studies of flammability of methanol in air were reported by Markus [21], Brooks [22] and Chang [23,24]. In the utilization of methanol fuel, much work was concentrated on the combustion and emission characteristics of the engines fueled with pure methanol [25,26], gasoline–methanol [27], diesel/methanol blends [28–31] or liquefied petroleum gas/methanol [32].

The data found in the literature are however not sufficient to rate the effects of an explosion. Normally, the following properties are used to describe the effect of an explosion: explosion pressure p_{ex} and maximum explosion pressure p_{max}, pressure rise (dp/dt) and the maximum rate of pressure rise $(dp/dt)_{max}$, as well as the deflagration index "K_G value" [33].

The maximum explosion pressures, the maximum rates of pressure rise, the explosion delay time and the deflagration index are important values for vent area design [34,35], for the explosion protection measure "constructive explosion protection" [33] and for the characterization of explosion transmission between interconnected vessels [36,37]. Measured explosion parameters of

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* Corresponding author. Tel.: +40 21 316 79 12; fax: +40 21 312 11 47.
E-mail address: maria_mitu@icf.ro (M. Mitu).

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Nomenclature

p	pressure (bar)
T	temperature (K)
K	deflagration index
t	time (s)
V	volume (L)
S	burning velocity (cm s^{-1})
R^2	the regression coefficient
r	radius

Greek letters

θ	time to peak pressure
Φ	diameter
Δ	variation
φ	equivalence ratio of fuel–oxidant mixtures

Subscripts

0	initial value
b	referring to burned mixture
c	cylinder
ex	explosion
G	referring to gas explosions
max	maximum value
pp	parallel piped
s	sphere
u	referring to burning velocity

methanol–air mixtures in a wide range of initial conditions are needed for extending databases of explosion parameters of fuels.

The laminar burning velocity is one of the basic parameters in combustion science. The laminar burning velocity is used for validating chemical reaction mechanisms and for modeling turbulent combustion. Therefore, the accurate determination of the laminar burning velocity is of great interest. The laminar burning velocity is fundamentally important in predicting the performance and emissions of the internal and external combustion systems [38].

The aim of this paper is to characterize the explosion characteristics of methanol–air mixtures (explosion pressure, rate of pressure rise, deflagration index and laminar burning velocity) in closed vessels, at different initial conditions (concentration, pressure and temperature).

2. Experimental set-up and procedure

2.1. Experimental set-up

The experimental set-up according to EN 15967 [39] (see Fig. 1) consists of a 5 L spherical stainless steel vessel pressure resistant up to 30 bar, an evaporator tube, a mixing vessel, metering devices for methanol and air and a heating chamber. The explosion vessel was equipped with a piezoelectric 10 bar pressure transducer connected to the data acquisition system for measuring the explosion data, a piezoelectric 2 bar pressure transducer to adjust the initial pressure, an ignition source and lines for evacuating the vessel, feeding the methanol/air mixture and exhausting the burned mixture. The pressure transducers were mounted flush with the inner wall of the vessel.

A series of induction sparks generated between stainless steel electrodes was used as an ignition source. The tips of the electrodes were positioned at the center of the vessel. The distance between the tips was (5 ± 0.1) mm. The mounting of the electrodes was resistant to the heat and pressure generated during the tests and provided adequate electrical resistance from the test explosion vessel. A high voltage transformer (root mean square: 13–16 kV; short circuit current: 20–30 mA) was used for producing the series of ignition sparks. A timer was used to set the required discharge time of 0.2 s.

The explosion vessel as well as the mixing chamber and the evaporator tube were positioned in a heating chamber which allows adjusting the temperature of the equipment to ± 2 °C.

The methanol was metered by using a volumetric pump; the air was metered by using a mass-flow controller.

2.2. Procedure

The explosion vessel, the mixing chamber and the evaporator tube were heated to the desired temperatures. The vessel was evacuated to a pressure $\leqslant$2 mbar, filled slowly with the methanol–air mixture to 1 bar, purged by 2 times its volume and then, if necessary, the initial pressure was reduced again to the desired one. Before ignition, the mixture was allowed to become quiescent and thermally equilibrated (3–5 min). Care was taken not to warm up the equipment by explosions which were too frequent.

The methanol–air mixtures were prepared by mixing together flows of air and methanol vapor. The methanol vapor is generated by metering the necessary amount of the liquid methanol into the evaporator tube. To homogenize the methanol–air mixture completely, it was led through the mixing chamber. The equipment for preparing the test mixture fulfills the requirements of EN 15967 [39] which was proven by analyzing the flammable substance content for the test mixture as an example using a total

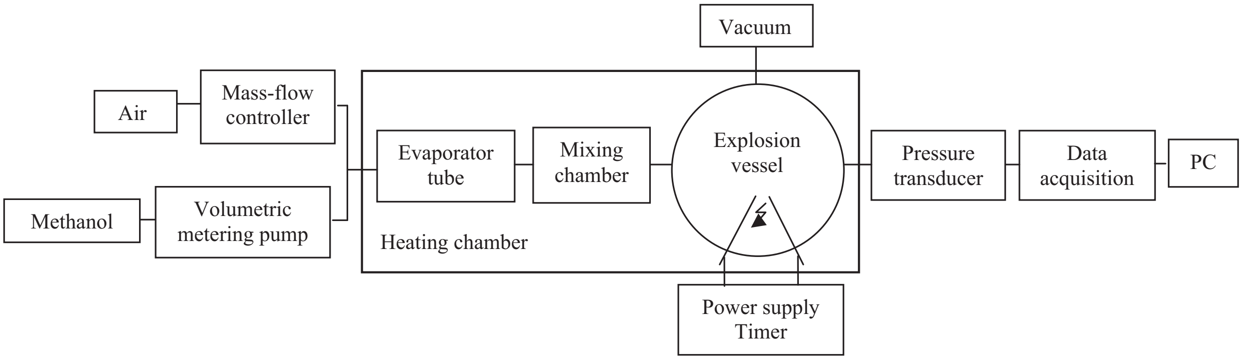

Fig. 1. Experimental set-up; schematic view.